Lubrication between viscoelastic bodies: theory & experiments

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We describe a fully general numerical methodology to deal with the lubrication between soft solids exhibiting linear viscoelastic rheological properties. We show that there occur significant deviations from classic elasto-hydrodynamic theory in terms of film thickness, pressure distribution and friction. Specifically, our results, corroborated by experimental outcomes, reveal that viscoelastic lubrication is fully governed by three parameters: the Hersey number and the dimensionless velocities of the two contacting bodies.

Keywords: lubrication, soft materials, viscoelasticity, friction.

Assessing the main peculiarities of lubrication between soft viscoelastic solids is a crucial issue that has only recently raised the attention of the lubrication science community. Indeed, in the last decades, massive research efforts have been dedicated to understand the role of non-Newtonian lubricants, but very little has been done to determine what occurs when the lubricated solids are not linearly elastic, and are instead characterized by a different rheology.

In this work, an innovative numerical methodology is presented to analyze the lubrication regimes between linear viscoelastic layers. In detail, an explicit finite difference scheme is coupled to a Boundary Element solver: this enables the study of the viscoelastic lubrication without any limitation in terms of material properties, geometry and viscosity. We focus on the simple tribological scheme reported in Figure 1:

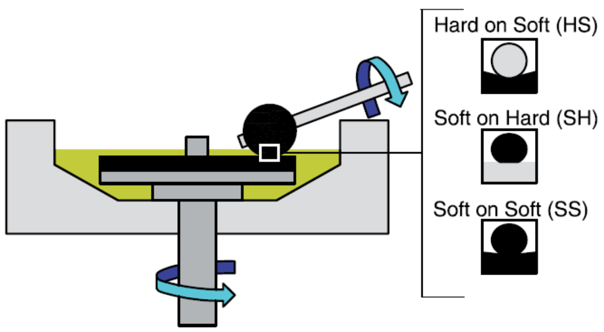

Figure 1: The system under investigation is schematically represented. Three configuration are considered: hard ball on soft disk (HS), soft ball on hard disk (SH), soft ball on soft disk (SS).

The results and, specifically, the film thickness, the contact pressure and, ultimately, the friction force show marked differences in comparison with classic lubrication theory. All this is validated by means of experiments specifically developed to deal with soft matter. In particular, to measure the film thickness, an innovative technique based on interferometry for soft solids [1] has been employed.

To point out the main features of the proposed numerical approach, let us focus on the simplest scheme in Figure 1, that is, the lubricated contact between a hard ball and a rubbery disk. For very low values of the speed, the deformable solid is in the elastic rubbery region and behaves, consequently, as a soft elastic body: no viscoelastic effect is present. When looking at the lubricating film, as expected (see e.g. Ref. [3,4]), we observe an almost perfectly circular shape and, due to the flow conservation, a minimum at the fluid inlet can be observed. However, something different occurs when the speed is increased. Indeed, the contact zone gradually evolves towards a shape that is increasingly far from a circle and is affected by a sharp shrinkage at the fluid outlet. In in agreement with analogous results in dry conditions, the contour plots of the fluid pressure clearly reveal a pressure peak that increases with the speed and produces, ultimately, a strong asymmetry towards the contact inlet.

Finally, as shown in detail in Ref. [2], the analysis of the other two configurations (SH and SS), show that viscoelastic lubrication is fully governed by three parameters: the Hersey number and the dimensionless velocities of the two contacting bodies.

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References

[1] Marx N, Guegan J, Spikes H, A, Elastohydrodynamic film thickness of soft EHL contacts using optical interferometry Tribology International, 99, 267-277, (2016).

[2] Putignano C and Dini D., Soft matter lubrication: does solid viscoelasticity matter?, ACS Applied Materials & Interfaces, 9 (48), 42287-42295, (2017).

[3] Putignano C Soft lubrication: A generalized numerical methodology, Journal of the Mechanics and Physics of Solids 134, 103748, (2020).

[4] Sadowski P., Stupkiewicz S., Friction in lubricated soft-on-hard, hard-on-soft and soft-on-soft sliding contacts Tribology International, 129, 2019, 246-256 (2019).